PB82-118175

Effects of Sulfur Oxides and Respirable Particles on Human Health

Harvard Medical School
Boston, MA

Prepared for

Health Effects Research Lab.
Research Triangle Park, NC

Oct 81

U.S. Department of Commerce
National Technical Information Service
NTIS.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RE
EPA-600/J-79-139	JOURNAL ARTICLE	PB82-118175

4. TITLE AND SUBTITLE	5. REPORT DATE
Effects of Sulfur Oxides and Respirable Particles on Human Health	October 1981
	6. PERFORMING ORGANIZATION CODE 307084

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
B.G. Ferris, F.E. Speizer, J.D. Spengler, D. Dockery, Y.M.M. Bishop, M. Wolfson, and C. Humble	

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Harvard School of Public Health Harvard Medical School 665 Huntington Ave Boston, MA 02115	CAGA1D
	11. CONTRACT/GRANT NO. 68-02-3201

12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Office of Research and Development (RTP,NC) Health Effects Research Laboratory US Environmental Protection Agency Research Triangle Park, NC 27711	14. SPONSORING AGENCY CODE EPA-600/11

15. SUPPLEMENTARY NOTES

Published In: American Review of Respiratory Disease, 120: 767-779, 1979

16. ABSTRACT

As part of a study of health effects of sulfur dioxide and particulate matter, we have established a cohort of adults 25 to 74 yr of age in 6 communities who will be followed prospectively. At the conclusion of our first cycle of measuring the health of adults in 6 sites we found that, although we used different sampling frames, our samples were close to the distribution shown in the U.S. Census for age, sex, and occupation, with the possible exception of one city.

Analysis of the cross-sectional data indicated that for both age and height-adjusted values for forced expiratory volume in 1 s and for selected rates of various respiratory symptoms standardized for age, differences among smoking groups were apparent. Differences in these parameters between sites suggest trends that were associated with levels of pollution. Further analyses of the prospective data currently being collected will be required before definitive statements can be made about specific levels of exposure.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

EPA-600/J-79-139
Journal Article

Effects of Sulfur Oxides and Respirable Particles on Human Health

Methodology and Demography of Populations in Study[1-3]

B. G. FERRIS, JR., F. E. SPEIZER, J. D. SPENGLER, D. DOCKERY, Y. M. M. BISHOP, M. WOLFSON, and C. HUMBLE

SUMMARY

As part of a study of health effects of sulfur dioxide and particulate matter, we have established a cohort of adults 25 to 74 yr of age in 6 communities who will be followed prospectively. At the conclusion of our first cycle of measuring the health of adults in 6 sites we found that, although we used different sampling frames, our samples were close to the distribution shown in the U.S. Census for age, sex, and occupation, with the possible exception of one city.

Analysis of the cross-sectional data indicated that for both age- and height-adjusted values for forced expiratory volume in 1 s and for selected rates of various respiratory symptoms standardized for age, differences among smoking groups were apparent. Differences in these parameters between sites suggest trends that were associated with levels of pollution. Further analyses of the prospective data currently being collected will be required before definitive statements can be made about the effect of specific levels of exposure.

Introduction

The National Air Quality standards and a description of the reference methods for 6 primary pollutants were originally promulgated in the Federal Register April 30, 1971 (42 CFR 410) and recodified November 25, 1972 (40 CFR 50). The 6 pollutants were suspended particulate matter, sulfur dioxide (SO_2), carbon monoxide, nitrogen dioxide (NO_2), photochemical oxidants, and hydrocarbons. No standard was established for sulfates. The standards set for these pollutants were based on the best evidence available at that time. Since their promulgation, there has been concern about whether the standards are adequate, and if not, to what extent they should be changed.

An extensive and provocative series of epidemiologic studies to evaluate the adequacy of these standards has been carried out by the Environmental Protection Agency (1). In addition, there have been occasional smaller efforts to assess the impact on the health of selected communities in this country (2–4) and abroad (5, 6). All of these studies have been subject to some criticism. Some of the studies have suffered from a lack of comparability between portions of the study populations because of the nonrepresentativeness of both the population samples and the air samples assessed, or because of the use of

(Received in original form October 16, 1978 and in revised form June 4, 1979)

[1] From the Harvard School of Public Health and The Channing Laboratory, Department of Medicine, Harvard Medical School, and Peter Bent Brigham Hospital, Boston, Mass.

[2] Supported in part by grants ES00002 and ES01108 from the U.S. Public Health Service, EPRI Contract no. RP1001-1, and Environmental Protection Agency Contract no. 68-02-3201.

[3] Requests for reprints should be addressed to B. G. Ferris, Jr., Harvard School of Public Health, 665 Huntington Ave., Boston, Mass. 02115.

[4] Copies of all initial and follow-up questionnaires and directions for their use are available on request.

poorly standardized equipment. Other studies have involved populations exposed to specific effluents, such as those from pulp mills (2), that may or may not be representative of populations in other communities. Other investigators have studied occupational groups, and their findings may have limited use or are not applicable to the general population.

In many studies the assessment of exposure was made on the basis of historical information or by extrapolation from single fixed monitoring sites. In some studies modeling was used to estimate the general levels of exposure. At times, these estimates have been verified by local measurements. Even with the delineation of the isopleths of pollution in a community, only rough estimates of the actual exposure of the residents can be obtained. Furthermore, most persons spend much time indoors, but few epidemiologic studies have monitored indoor air to determine the differences between indoor and outdoor air (7).

To try to resolve some of these difficulties and to obtain comparable data from a variety of communities with differing levels of pollution, the present study was developed. This study had 2 components: (*1*) measurement of the concentrations of air pollutants, especially SO_2, sulfates, and respirable particulate matter; and (*2*) determination of the effects of these concentrations of pollutants on the health of adults and children on a prospective basis.

This paper presents the over-all design of the study and the nature of the populations selected for evaluation. We compared the demography of the communities from which the populations were selected and the persons actually participating in the study. The historical or previous levels of exposure to atmospheric pollutants were considered along with a description of the data to be obtained from the assessment of health and exposures.

Methods

Sites selected. The following criteria were used for selecting the various sites: (*1*) A reasonable amount of historical data on the levels of pollution was available. (*2*) The population was relatively stable. (*3*)

TABLE 1

SAMPLING FRAMES AND METHODS OF SELECTION FOR ADULTS IN 6 CITIES

Site, Date Sampled	Listing Used	Selection Method	Sampling Method*
Watertown, Mass. Fall 1974	Precinct listing, 1/1/1974	By street; resident's age was given	Every ninth person 25–74 yr of age
Kingston-Harriman, Tenn. Spring 1975	Mullin-Kille Resident Directory for Kingston, Tenn. Harriman included (copyright by R.M. Baldwin), 1974	Alphabetic, by name of person or business	Random selection of pages for individual person or for husband-wife pairs
St. Louis Mo. (Carondolet Area) Fall 1975	St. Louis City Directory, R.L. Polk Co., 1974	By street	Random blocks selected from city map (one side of block and one side of street selected at random), with individual person or husband-wife pairs included.
Steubenville, Ohio Spring 1976	Steubenville City Directory, Burch Directory Co., 1974	Alphabetic, by name of person or business	Random selection of entries from randomly selected pages for individual persons or for husband-wife pairs
Portage, Wis. (including Wyocena and Pardeeville) Fall 1976	a. Portage Directory, Johnson Publishing Co., 1975 b. Wisconsin Survey Res. Lab. made census of Wyocena and Pardeeville, 1976	Alphabetic, by name of person or business	a. Every third name of individual persons or husband-wife pairs. b. Random sampling of houses from survey with individual persons or husband-wife pairs included
Topeka, Kan. Spring 1977	Topeka City Directory, R.L. Polk Co., 1975	Alphabetic, by name	Selection of entries from randomly selected pages for random individual persons or husband-wife pairs

* In every city, students and members of religious orders were excluded.

The population was approximately 50,000 persons to ensure that sample sizes of 1,500 adults would be available, and to ensure that by using all of the local schools we could obtain adequate numbers of children. (4) The population included no confounding large occupational group, such as underground coal miners. (5) The number of sources of different types of air pollution was small. (6) The ethnic mix was not too heterogeneous. (7) State and local health departments and boards of education agreed to cooperate.

The actual sites selected were Watertown, Mass.; Kingston-Harriman, Tenn.; the southern end of St. Louis, Mo., defined by specific census tracts; Steubenville, Ohio; Topeka, Kan.; and Portage, Wis.

Selection of adult population. Adults were selected from various census lists (household voting lists or private census for commercial listings). Selection was random and involved part of a block from a street listing or selection of names from an alphabetized list. The exact method used depended on the available material and its format (table 1).

Because the sampling frames in the 6 cities were constructed at different times and in different ways, the initially selected samples varied between 2,174 and 3,583 persons (table 2). After excluding persons who were outside the designated age range (25 to 74 yr of age), were dead, had moved, were hospitalized or too ill, or were actually residing outside the study area, we were left with 47 to 82 per cent of the original samples in each city. The over-all response rate for the age-eligible, available populations was 76.8 per cent, with the highest response rate in Portage, Wis. at 80.9 per cent and lowest response rate in Watertown, Mass. at 72.5 per cent (table 2, column D).

The first city was initially visited in fall 1974; the next city, in spring 1975. Two more cities were visited in 1975 to 1976; and the last 2, in 1976 to 1977. The plan was to follow the adults every 3 years, so the first city, Watertown, Mass., was revisited in fall 1977; Kingston-Harriman, Tenn., in spring 1978; and St. Louis, Mo., in fall 1978. To ensure that loss of subjects due to change of address was minimized, a newsletter was sent to each participant each year. For deceased persons about whom we were notified by the post office or we discovered at the time of the follow-up, death certificates were obtained. These were used to determine whether there were any differences in the over-all mortality rates among the various cities and whether there were differences in the causes of death. Of the 1,287 participants originally seen in Watertown, Mass. in 1974, we reinterviewed 960 in 1977. An additional 80 of 112 eligible volunteers from 1974 were seen again.

Selection of population of children. The children initially selected included all first- and second-grade school children in each community. In the Portage, Wis. area, the numbers were small, so we initially selected the children from grades 1 through 4. This resulted in a different age distribution for this one city, but all comparisons between cities were age adjusted. In Topeka, Kan., because of its size, somewhat more than one half of the schools were selected at random. Parochial school children were included as a part of the sample. All school children were resurveyed annually, and during the first and second resurveys, new first-grade school children were added to the study if the number of children in that community was less than 1,500.

In each community, the school children were first seen at the same time as the adults. Thus, by June 1977 3 cohorts had been accumulated in the first 2 towns; 2 cohorts in the next 2 towns; and one cohort in each of the last 2 towns. The rate of refusal, i.e., refusal of the parents to allow their children to participate, was very low, not exceeding 5 per cent in any school. We had no refusals from the school systems that were most cooperative. The number of

TABLE 2

CRITERIA FOR DECREASE IN SELECTED POPULATION TO AGE-ELIGIBLE, AVAILABLE POPULATION, BY CITY

	A	B					C	D†
	Sample Drawn	Moved	Dead	Outside Area or Not Locatable*	Hospitalized or Too Ill	Outside Age Range	Eligible (*no.*) (% of A)	Seen (*no.*) (% of C)
Watertown, Mass.	2,174	297	7	3	44	48	1,775 (81.6)	1,287 (72.5)
Kingston-Harriman, Tenn.	3,583	349	53	1,255	41	205	1,680 (46.9)	1,355 (80.7)
St. Louis, Mo.	2,828	442	86	118	33	405	1,734 (61.3)	1,386 (79.9)
Steubenville, Ohio	3,207	475	154	205	72	345	1,956 (61.0)	1,426 (72.9)
Portage, Wis.	3,113	187	83	251	31	494	2,067 (66.4)	1,672 (80.9)
Topeka, Kan.	3,174	383	56	573	39	295	1,828 (57.6)	1,354 (74.1)
Total, all cities	18,079	2,133	439	2,405	260	1,802	11,040 (61.1)	8,480 (76.8)

* The vast majority were persons who lived on rural routes more than 10 km from the center of each town being studied.
† The number seen from a random sample. We also had volunteers in each city.

schools participating varied from 2 to 18 public schools and zero to 9 parochial schools per community. Children in 51 public and 21 parochial schools are currently being followed.

Assessment of health effects. The assessment of health effects in adults was made by personal interviews using a standard questionnaire[4] and simple tests of pulmonary function by trained nonmedical interviewers. The questionnaire concerned respiratory symptoms, tobacco smoking habits, and occupational and residential history. This was a modified version of the British Medical Research Council Questionnaire that has been used for 15 years in population studies in the United States and Canada; it is similar to the newly devised Division of Lung Disease Questionnaire (2, 8–10).[4]

A different procedure was followed for the children. An explanatory letter and a questionnaire to be completed by the parent or guardian were sent home with the child from school. The questionnaire asked about living conditions, type of fuel for cooking and heating system, occupation and smoking habits of parents, family composition, and previous respiratory illnesses of the child and of the parents. The questionnaire also contained a permission form. The child returned the signed form in a sealed envelope to school, where it was given to a member of the research team. The older children (fourth grade or more) were asked about their cigarette smoking habits by means of a standard short questionnaire when their pulmonary function was measured.

In both adults and children, pulmonary function measurements were made on a low-resistance, low-inertia, water-filled Stead-Wells recording spirometer. Portable models of the same machine were used at the central interviewing site and for home visits. The portable spirometers have exactly the same response characteristics as the larger table-top model. The main difference (and advantage) is that, when filled with water, the portable machine weighs 17 pounds compared with the 55 pounds of the table-top machine. The spirometers were checked regularly for leaks and accuracy. The tubing was washed and sterilized weekly by soaking in a quaternary amine sterilizing solution overnight.

Adults performed forced vital capacity (FVC) maneuvers on the machines while in the sitting position, without nose clip, either at the central station or at home. The childrens' pulmonary function was measured without nose clip while they stood in the classroom. The procedure was to record 5 forced expirations and to use the average of the best 3 to represent the "true" value. Failure to make at least 3 satisfactory blows in 5 attempts prompted a request for further efforts, to a maximum of 8 trials.

From the spirometer tracings, the FVC and the forced expiratory volume in 1 s (FEV_1) were read. To be acceptable, FVC traces had to be at least 6 s in duration; for traces shorter than 6 s, we accepted only those that reached an asymptote. Durations of 3 s were acceptable in children. All traces that did not contain gross errors or irregularities were read and recorded. A computer program was used to convert ambient temperature values to BTPS, to delete "outliers," and to calculate the average of the 3 best efforts (11).

Procedure. The 2 survey teams included a core of permanent staff that moved from site to site. Each year, one group surveyed the adult population and the children in 2 cities, and the other group saw the children in the other 4 sites. Additional interviewers were hired locally. A week or more was used as a training period for the new interviewers to become accustomed to the questionnaire and to learn the criteria for adequate tests of pulmonary function. The permanent core acted as a standard group of interviewers, permitting us to determine the comparability of the recruited interviewers. In addition, the coprincipal investigators (BF and FS) visited and interviewed adults at each site for 1 to 2 weeks.

Each adult subject selected was sent an explanatory letter about the study and was asked to participate by being given a specific appointment in the central station clinic. Arrangements were provided for the person to change the appointment to a more convenient time. For persons who could not or would not come to the central station clinic, home visits were made. Thank-you letters were sent to all participants. Annual reports were also sent to all participants. All data were kept confidential, except that with the permission of the subjects, results were made available to their physicians or, in general terms, to themselves.

In the children's survey, a school contact (usually the school nurse or principal) notified the research team when the forms for a particular classroom were returned. A schedule was set up for the team to come to the classroom, where the children performed the tests of pulmonary function and had their height and weight measured. Three to 4 classrooms could be visited each day. The questionnaires were reviewed for completeness. Missing data were requested by telephone calls to the parents.

Air monitoring. Air quality monitoring was performed in each community in an attempt to quantify population and individual exposures to SO_2, mass respirable particles, sulfates, NO_2, and ozone. The nonrespirable fraction of airborne particles was removed by a cyclone presampler: 90 per cent of the 1-μm particles and 50 per cent of the 3.5-μm particles passed through the presampler. None of the particles with aerodynamic diameters > 10 μm passed through the cyclone presampler. Three types of air monitoring were instituted in to attempt to estimate the exposure to pollutants of residents of each community. These were continuous fixed-location sampling at a central station, indoor-outdoor monitoring, and personal monitoring.

Continuous monitoring equipment in each community was located at a site representative of the

total residential exposure. From these primary sites, the hourly average concentrations of SO_2, NO_2, and ozone were recorded. In addition, the meterologic parameters, wind speed and direction, temperature, and dewpoint, were recorded; 24-hour integrated samples were taken of the following pollutants every 3 days at the central station: total suspended particulate matter (TSP), mass respirable particulate matter (MRP), NO_2, and SO_2.

The relationship between ambient outdoor and indoor concentrations of pollutants was measured in at least 10 sites in each city. Twenty-four-hour integrated samples for SO_2, NO_2, and MRP obtained simultaneously within the house and directly outside it were collected every 6 days, which coincided with every other similar sample collected at the central site. Volunteers consented to at least 1 full year of monitoring. Indoor samples were taken in the room in the home where the family spent the most time. Bedrooms, kitchens, and bathrooms were not monitored.

Three days per week, during a 6- to 8-week period, selected volunteers from the health survey sample carried a personal monitor with them. This monitor collected a 24-hour integrated sample of the MRP; a similar monitor was placed in the home to sample the indoor environment. To help correlate data with exposure, the volunteer kept a record of all activities at 30-min intervals on the sampling day. Sampling days were Monday, Wednesday, and Friday for a total of 20 or more sampling days. It is planned to do this in all communities at different times of the year.

The collected samples were analyzed for total mass, water-soluble sulfate, and, on a selected basis, for various elemental constituents of the particles by atomic absorption, neutron activation, and electron spectroscopy for chemical analysis. A special method was needed to analyze for sulfate because of the small mass collected; this method was developed (Wolfson JM: Microanalysis of atmospheric particulate sulfate, unpublished data).

Demography. Census data for each community were obtained from the publications of the U.S. Census Bureau for the year 1970. These data provided information on distributions of age, sex, race, income, and occupational categories and allowed us to compare the distributions of these variables in populations participating in the study.

Statistical methods. Comparisons of observed distributions by age and sex with the 1970 census were made using a program called "Loglin" (12). This program computes maximal likelihood expected values under different models, and compares the overall goodness of fit by the likelihood ratio statistic, G^2. This statistic is then referred to the chi-square distribution with appropriate degrees of freedom (df). The program also transforms the difference between observed and expected values by means of the Freeman-Tukey Poisson transformation. These transformed deviates are approximately normally distributed with mean of zero and variance of one (13).

The pulmonary function statistics were adjusted for age and height using least-squares regression and a standard statistical package. Outlying values were previously discarded (11). The difference between the observed pulmonary function values and the values predicted by this regression were computed for each subject. These individual residuals were then analyzed by 2-way analysis of variance to evaluate city effects, smoking effects, and whether there was a city-by-smoking interaction.

Results

Effectiveness of sampling. The communities selected were chosen to provide a gradation of anticipated exposure to pollution from well below the current Federal primary standards to well above the standards. Data existing at the time and information of the expected change during the course of the next 5 to 10 yr were used to provide 2 sites each at "low," "medium," and "high" levels of exposure (figure 1). Portage, Wis. and Topeka, Kan. were well below the standards for SO_2 and TSP. Kingston-Harriman, Tenn. was at the standard for TSP. Although Watertown, Mass. was well below the standards for SO_2 and TSP, the reported sulfate

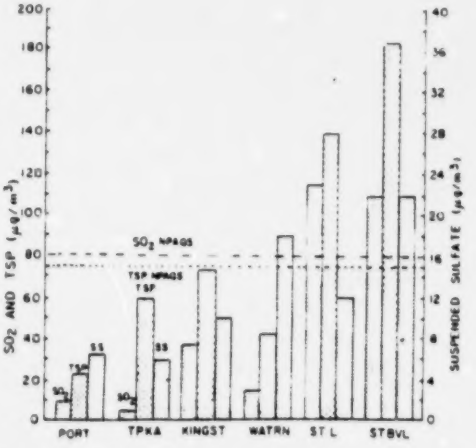

Fig. 1. Historical pollution levels in each city, quantified as concentrations of sulfur dioxide (SO_2), total suspended particulate matter (TSP), and suspended sulfates (SS). Dotted lines labeled SO_2 NPAQS and TSP NPAQS are National Pollution Air Quality Standards (annual averages) for SO_2 and TSP, respectively. Cities are Portage, Wis. (PORT), Topeka, Kan. (TPKA), Kingston-Harriman, Tenn. (KINGST), Watertown, Mass. (WATRN), St. Louis, Mo. (St. L), and Steubenville Ohio (STBVL).

TABLE 6

OCCUPATIONAL DISTRIBUTION OF SAMPLE COMPARED WITH EXPECTED NUMBER FROM CENSUS*

Occupation		Numbers of Persons						
		Portage, Wis.	Topeka, Kan.	Watertown, Mass.	Kingston-Harriman, Tenn.	St. Louis, Mo	Steubenville, Ohio	% Sampled
Professional	Observed	149	221	223	162	71	127	
	Expected	157.0	200.5	248.9	*117.8*†	*107.5*	121.3	4.8
Managerial	Observed	83	85	58	61	37	66	
	Expected	84.8	72.7	69.3	62.3	40.2	60.8	4.0
Clerical	Observed	241	338	277	160	256	209	
	Expected	219.1	327.9	302.3	157.7	281.2	217.8	4.0
Craftsman	Observed	310	164	210	298	246	235	
	Expected	315.0	178.9	*177.0*	*374.7*	*207.0*	210.4	4.3
Transport operator	Observed	146	96	117	119	112	97	
	Expected	156.8	*121.4*	*85.5*	108.6	93.1	*121.6*	3.4
Laborer	Observed	36	25	16	36	27	36	
	Expected	36.2	25.4	17.6	39.2	19.6	38.0	2.5
Farmer	Observed	51	2	0	6	0	0	
	Expected	52.2	4.2	0.3	1.8	0.3	0.2	2.4
% of Population Represented‡		8.4	2.2	5.9	20.2	4.7	8.5	

* Census was for work force ≥ 16 yr of age; our sample included those ≥ 25 yr of age.
† Underlined values indicate that the Freeman-Tukey deviate between observed and expected was greater than 2.
‡ Analysis based only on persons currently employed in these categories.

seem that the Kingston-Harriman sample diverged most from expectation, and that the other cities were close to expectation.

We concluded that, as far as age, sex, and occupation were concerned, our respondents represented reasonably comparable samples from each city, with the possible exception of Kingston-Harriman. If we find that a particular age group or socioeconomic class seems to be particularly affected by air quality, we will have to investigate further the composition of the respondents to ensure that the Kingston-Harriman sample was not biased by including, for instance, an excess of persons from a particular industry who were worried about their health.

Baseline health of adults. The design of the study is such that new children are still being entered. Because all 6 cities have been visited, we have our total planned sample of adults and can make some between-city comparisons of the health status of these adults. Such comparisons should be viewed with caution, because adults have had a lifetime of exposure to a variety of sources of pollutants; their health at a specific point in time cannot be entirely attributed to the current air quality of the city in which they are residing at that point in time. We know which participants were long-term residents of each region, but even comparisons between such groups are subject to bias. Persons adversely affected by a particular pollutant may move away and thus not become long-term residents of such a region. Moreover, long-term historical air pollution values are not readily available. Thus, the study was designed to measure changes with time while the participants were residents in the city. Nevertheless, it is of interest to compare baseline measurements in each city.

Lung function results. The most objective measurements collected were the lung function measurements. We needed to correct these for the height and age of each adult. To determine the appropriate correction factor, we took all 6 cities (excluding volunteers) and examined (*1*) all participants, and (*2*) all white nonsmoking asymptomatic participants. Nonsmokers were persons who had never smoked tobacco. Asymptomatic persons were defined by the following answers to specific questions: (*1*) They did not have a cough, did not bring up phlegm from their chest, did not wheeze, and were not short of breath. (*2*) They had never been told by a doctor that they had bronchitis, emphysema, pneumonia, bronchial asthma, or any other chest illness, operation, or injury.

We chose to use the regression for the white

healthy (asymptomatic) persons who had never smoked as our standard. These equations gave slightly higher predictions for each lung function value for each sex than we would have obtained had we used the regression on the total sample as our standard (table 7). The deviations from the standard expectation were computed for each adult, and these were analyzed to determine how they varied according to smoking habit and city. Smoking habits were classified in 2 ways. An estimate of lifetime cigarette smoking was obtained by asking respondents the number of packs of cigarettes they currently smoked each week and how this had varied in previous years. (Hand-rolled cigarettes were included by converting the amount of tobacco smoked assuming 1 g/cigarette.) Respondents were also classified by their current smoking status. The 5 classifications were "never smoked"; "ex-smokers," if they had not smoked for at least 6 months; "pipe and cigar," if they did not smoke cigarettes; and 2 groups of cigarette smokers, those who smoked ≤1 pack/day, and those who smoked >1 pack of 20 cigarettes/day.

By analysis of variance, the FVC and FEV_1 residuals varied significantly by city and by the 5 current smoking categories. For men, there was no evidence of an interaction effect of smoking and city (figure 2). For women, 4 current smoking categories were analyzed: pipe and cigar smokers were so rare that this category was excluded. Women showed some evidence that the smoking effect varied between cities ($P = 0.043$ for FVC and $P = 0.043$ for FEV_1). This interaction seemed largely to be due to the differences between cities in the relative ranking of the smokers and ex-smokers (figure 3). The relative ranking of the cities was not reproducible, but for each of the 4 analyses (2 sexes and 2 pulmonary function measurements) the 2 lowest values were found in Kingston-Harriman and St. Louis, whereas Portage had either the highest or second-highest values.

The lifetime totals of cigarettes smoked were divided into the following 5 categories: "never," <3,000 packs; 3,000 to 8,999 packs; 9,000 to 17,999 packs; and ≥18,000 packs. For both sexes the effect of these smoking categories was a monotonic decrease in lung function. The decrease was more marked for FEV_1 than for FVC for each sex, and was more pronounced for men than women (table 8). The rank ordering of

TABLE 7

REGRESSION OF LUNG FUNCTION VALUES ON HEIGHT AND AGE FOR DIFFERENT GROUPS OF ADULTS (ALL CITIES COMBINED)

	Coefficients					
	Constant	Age (*yr*)	Height (*cm*)	N*	R^2	Prediction for Average Person† (L)
FVC						
Men						
White, asymptomatic, never smoked	−3.425	−0.0291	0.0539	449	0.531	4.429
Total sample	−1.651	−0.0370	0.0444	3,668	0.476	4.232
Women						
White, asymptomatic, never smoked	−0.642	−0.0259	0.0313	1,296	0.516	3.232
Total sample	−0.555	−0.0280	0.0309	4,489	0.495	3.160
FEV_1						
Men						
White, asymptomatic, never smoked	−2.055	−0.0285	0.0406	449	0.529	3.565
Total sample	−0.306	−0.0385	0.0315	3,668	0.484	3.317
Women						
White, asymptomatic, never smoked	0.455	−0.0268	0.0211	1,296	0.580	2.646
Total sample	0.459	−0.0282	0.0208	4,489	0.519	2.539

Definitions of abbreviations: FVC = forced vital capacity; FEV_1 = forced expiratory volume in 1 s.

* Persons were included only if values were available for both FVC and FEV_1.

† Predicted values for 45-yr-old men 170 cm tall and women 161 cm tall.

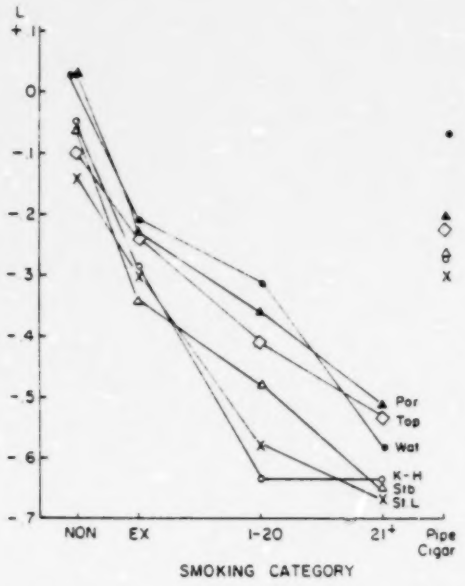

Fig. 2. Deviation from expected 1-s forced expiratory volume (ordinate), in liters (L), by smoking category for men in each city. Por = Portage, Wis.; Top = Topeka, Kan.; Wat = Watertown, Mass.; K-H = Kingston-Harriman, Tenn.; Stb = Steubenville, Ohio; St. L = St. Louis, Mo.; NON = nonsmokers; EX = ex-smokers; numbers on abscissa = number of cigarettes currently smoked/day; "Pipe, Cigar" denotes current smokers who did not smoke cigarettes.

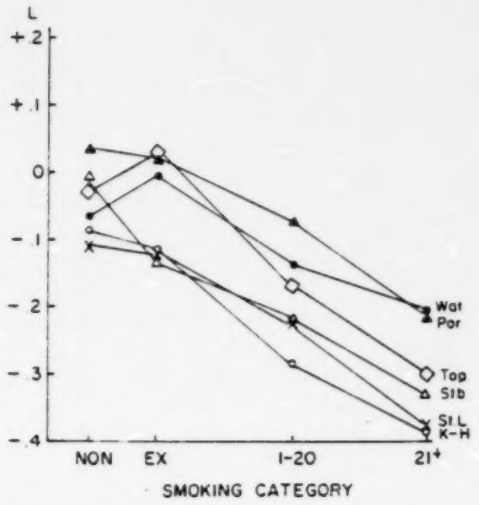

Fig. 3. Deviation from expected 1-s forced expiratory volume (ordinate), in liters (L), by smoking category for women in each city. For definitions of abbreviations see figure 2.

cities for these 4 analyses was the same as that for the current smoking, and the associated variance ratios were slightly smaller.

Reported disease symptoms. The answers to 2 of the specific health questions could be interpreted as indicating obstructive lung disease (the questions that elicit the positive responses, "wheezing most days and nights" and "shortness of breath when walking on the level at one's own pace"). A further measure of obstructive lung disease was a FEV_1 <60 per cent of the FVC. We looked at the data for all nonasthmatic respondents to determine the relative frequency of these symptoms of obstructive disease, and the extent to which more than one symptom occurred in the same respondent (table 9). The most commonly reported symptom was wheezing; approximately 7.3 per cent of men and 4.2 per cent of women reported this symptom, among those who did not report shortness of breath

TABLE 8

EFFECTS OF LIFETIME SMOKING ON RESIDUALS OF LUNG FUNCTION: DEVIATIONS AFTER CORRECTION FOR HEIGHT AND AGE

Lifetime Cigarettes Smoking (no. packs)	Deviation							
	Men				Women			
	FVC		FEV_1		FVC		FEV_1	
	(L)	(n)*	(L)	(n)	(L)	(n)	(L)	(n)
None	0.18	1,031	0.25	1,022	0.03	2,336	0.06	2,334
< 3,000	0.15	468	0.21	465	0.04	707	0.04	706
3,000 – 8,999	0.00	907	0.01	903	−0.02	862	−0.05	854
9,000 – 17,999	−0.15	888	−0.19	884	−0.12	509	−0.20	509
≥ 18,000	−0.33	409	−0.45	409	−0.23	94	−0.28	94

Definitions of abbreviations: FVC = forced vital capacity, in liters (L); FEV_1 = forced expiratory volume in 1 s; n = number of subjects.

* The numbers of persons differed slightly for FVC and FEV_1 when the number of outliers deleted varied.

TABLE 9

PREVALENCE OF INDICATORS OF OBSTRUCTIVE DISEASE

Sex	$FEV_1/FVC\%$ ≤ 60	Dyspnea	Wheeze			
			No	Yes	Total	Rate/1,000 Persons
Male	No	No	3,098	242	3,340	72.5
		Yes	54	23	77	298.7
	Yes	No	108	39	147	265.3
		Yes	8	26	34	764.7
Female	No	No	4,010	176	4,186	42.0
		Yes	87	35	122	286.9
	Yes	No	50	13	63	206.3
		Yes	8	12	20	600.0
Total			7,423	566	7,989	70.9

and did not have severely decreased FEV_1. We therefore chose to examine rates for reported wheezing using this symptom as an indicator of obstructive lung disease.

After adjustment for age, the rates of wheezing for each sex and for each smoking category provided some indication of differences between cities, but these differences were overwhelmed by the effect of cigarette smoking (figure 4). In every city, for both sexes, current smokers reported more wheezing than those who had never smoked. Men who had given up smoking generally had rates between those for nonsmokers and those for smokers who were currently consuming ≤1 pack/day. Female ex-smokers reported wheezing less often than nonsmokers in the cleaner cities, Portage and Topeka, and approximately equally often or slightly more often in the remaining cities. Similarly, the magnitude of the increase in rate of wheezing between those smoking ≤1 pack/day and those smoking >1 pack/day varied by sex and by city. These differences were not just random fluctuations. When we tried to fit a model that postulated that the sex-specific smoking effect was the same in each city, we found significant departures from the model. One reason for these differences might be that we had relatively coarse categories for the smoking effect; we might need a more sophisticated approach that takes into account lifetime burden. Another possibility is that other exposures, including occupational, contribute to wheezing. Thus, we cannot safely conclude from the present analysis that the apparent city-smok-

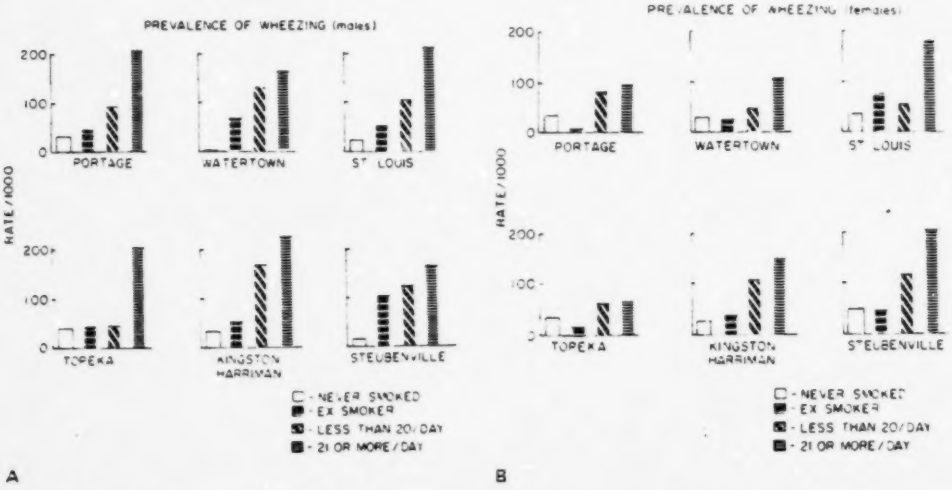

Fig. 4. Age-adjusted rates of reported wheezing, by smoking category and by city, for men and for women. Portage, Watertown, and St. Louis were visited in fall; Topeka, Kingston-Harriman, and Steubenville, in spring.

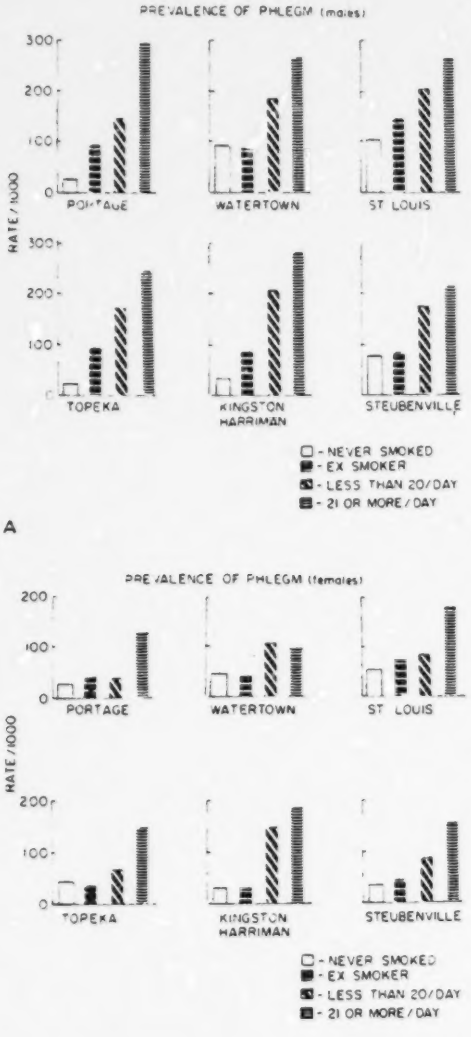

Fig 5. Age adjusted rates of reported phlegm production, by smoking category and by city, for men and for women. Portage, Watertown, and St. Louis were visited in fall; Topeka, Kingston-Harriman, and Steubenville, in spring.

ing-wheezing interaction demonstrates that the effect of cigarette smoking on wheezing differs according to the amount of air pollution. We can, however, look at the highest rates of wheezing (those for the heavy smokers) and observe that among women there was an increase in wheezing with increased air pollution in the cities visited in the spring; in ascending order these cities were Topeka, Kingston-Harriman, and Steubenville. To a lesser extent, the same ordering of wheezing rates corresponding to ordering by air pollution was apparent for the cities visited in the fall (Portage, Watertown, and St. Louis).

We also looked at rates of phlegm production (figure 5); respondents admitted that they produced phlegm "for three months of the year for three or more years." Again, there was a strong effect of cigarette smoking, and again, the relative rates for ex-smokers seemed to vary between sexes and between cities. When we looked at the categories "never-smoked," "smokes one pack a day or less," and "smokes more than one pack a day," we found an ordered increase for each sex for each city except Watertown. For Watertown, female heavy smokers reported slightly lower rates than smokers of fewer cigarettes. We did not find a consistent ordering of cities by air quality, except for male nonsmokers.

Discussion

From our preliminary analyses, we conclude that our sample of adults in each city is a good representation of the population in that city. Our primary measures of health effects are reported respiratory symptoms and measurements of lung function. The fact that this preliminary analysis revealed the expected effects of cigarette smoking and age on both these measures gives us confidence that the questionnaire and spirometry are effective means of assessing these parameters of health.

The study was designed to measure changes in these parameters with time. Any differences found between cities in a cross-sectional examination of adults may be attributed to past events and such variables as socioeconomic status. Nevertheless, this preliminary analysis leads us to believe that our measurements may, indeed, reflect effects of current air quality on health, and we intend to pursue these analyses and determine what other variables may be affecting these populations. The ultimate test of the hypothesis must await the prospective collection of the data and their subsequent analysis.

References

1. U.S. Environmental Protection Agency. Health consequences of sulfur oxide: a report from CHESS, 1970-1971 (EPA publication no. [650/1-74-004]) Washington: U.S. Government Printing Office, May 1974.
2. Ferris BG Jr, Chen H, Puleo S, Murphy RLH

Jr. Chronic nonspecific respiratory disease in Berlin, New Hampshire, 1967 to 1973: a further follow-up study. Am Rev Respir Dis 1976; 113: 475–85.

3. Holland, WW, Stone RW. Respiratory disorders in United States East Coast Telephone Men. Am J Epidemiol 1965; 82:92–101.
4. Comstock GW, Stone RW, Sakai Y, Matsuya T, Tonascia JA. Respiratory findings and urban living. Arch Environ Health 1973; 27:143–50.
5. Holland WW, Reid DD. The urban factor in chronic bronchitis. Lancet 1965; 1:445–8.
6. Lunn JE, Knowelden J, Roe JW. Patterns of respiratory illness in Sheffield junior school children: a follow-up study. Br J Prev Soc Med 1970; 24:223–8.
7. Binder RE, Mitchell CA, Hosein HR, Bouhuys A. Importance of the indoor environment in air pollution exposure. Arch Environ Health 1976; 31:277–9.
8. Ferris BG Jr, Anderson DO. The prevalence of chronic respiratory disease in a New Hampshire town. Am Rev Respir Dis 1962; 86:165–85.
9. Anderson DO, Ferris BG Jr, Davis TW. The Chilliwack respiratory survey 1963. I. Methodology. Can Med Assoc J 1965; 92:899–905.
10. Ferris BG Jr. Epidemiology standardization project. Am Rev Respir Dis 1978; 118 (Suppl: 1–120).
11. Ferris BG Jr, Speizer FE, Bishop Y, Prang G, Weener J. Spirometry for an epidemiologic study: deriving optimum summary statistics for each subject. Bull Eur Physiopathol Respir (Nancy) 1978; 14:145–66.
12. Neff RK, Olivier DC. Loglin 1.0 user's guide. Boston: Health Sciences Computing, Facility of the Harvard University School of Public Health, 1976:1–89.
13. Bishop YMM, Fienberg SE, Holland PW. Discrete multivariate analysis: theory and practice. Cambridge, Mass.: MIT Press, 1975, 1976, 1977: 1–557.

TABLE 3

NUMBER OF RESPONDENTS IN EACH AGE GROUP, EXPRESSED AS A PERCENTAGE OF 1970 CENSUS TOTAL*

Age (yr)	Percentages Across All Cities		
	Men (%)	Women (%)	Both Sexes (%)
25-34	4.2	5.0	4.63
35-44	4.3	4.6	4.48
45-54	6.0	6.7	6.36
55-64	6.0	6.2	6.14
65-74	6.1	5.2	5.56
All ages	5.22	5.60	

* See table 6 for percentage sampled by city.

concentrations were relatively high. St. Louis, Mo. and Steubenville, Ohio were clearly above the current standards for both SO_2 and TSP. The suspended sulfate concentrations were also high: however, no current standards exist for sulfates.

To assess whether our samples of adults were representative, we compared their age and sex distributions to those of the 1970 census for each city or appropriate standard metropolitan statistical area. We knew that our sampling ratio varied between cities and suspected that it would, in general, vary by sex and by age. We were interested in determining whether the same age and sex pattern of participation was to be found in all cities. The over-all sampling rates were slightly higher for the older age groups and, for most age groups, higher for women than for men (table 3).

The proportion of the population sampled in each city varied from 2 per cent in Topeka, Kansas, to 20 per cent in Kingston-Harriman, Tenn. If the age-sex-city distribution sampled was the same as that recorded in the 1970 census, we could estimate the number of persons to expect in each category of the sample. Our hypothesis was that the over-all sampling fraction varied between cities, but that the variation by age and the variation by sex were the same for each city. Using this model we could estimate from the census tabulations how many men and how many women to expect in each age group in each city (Exp 1 in tables 4 and 5). The over-all fit of these expected values was poor (the likeli-

TABLE 4

COMPARISON OF AGE-SEX DISTRIBUTION OF MALE SAMPLE WITH EXPECTED VALUES (EXP 1 AND EXP 2) DERIVED USING DIFFERENT SAMPLING MODELS

Age (yr)		Portage, Wis.	Topeka, Kan.	Watertown, Mass.	Kingston-Harriman, Tenn.	St. Louis, Mo.	Steubenville, Ohio
25-34	Observed	175	140	142	100	103	88
	Exp 1	157.2	151.5	150.5	*121.5**	107.3	97.2
	Exp 2	181.5	150.6	151.3	106.8	102.9	92.3
35-44	Observed	161	103	99	109	97	92
	Exp 1	143.2	114.4	91.5	117.2	89.7	98.3
	Exp 2	152.9	112.6	100.5	99.9	93.1	96.6
45-54	Observed	178	160	137	178	154	170
	Exp 1	198.4	160.1	134.6	175.5	149.5	182.2
	Exp 2	177.9	172.0	132.0	180.3	155.3	181.6
55-64	Observed	171	111	107	152	132	173
	Exp 1	172.9	119.1	114.7	*123.2*	154.8	162.2
	Exp 2	177.2	114.3	110.4	150.1	129.9	167.5
65-74	Observed	113	80	74	78	134	95
	Exp 1	121.0	72.4	72.2	64.0	*95.8*	92.1
	Exp 2	104.3	68.8	70.1	64.9	112.9	93.4

* Underlined values indicate that the Freeman-Tukey deviate between observed and expected was greater than 2.

TABLE 5

COMPARISON OF AGE-SEX DISTRIBUTION OF FEMALE SAMPLE WITH EXPECTED VALUES (EXP 1 AND EXP 2) DERIVED USING 2 DIFFERENT SAMPLING MODELS

Age (yr)		Portage, Wis.	Topeka, Kan.	Watertown, Mass.	Kingston-Harriman, Tenn.	St. Louis, Mo.	Steubenville, Ohio
25-34	Observed	203	168	168	132	110	113
	Exp 1	*170.2**	158.2	157.7	142.0	114.6	112.1
	Exp 2	196.5	157.4	158.7	125.2	110.1	106.7
35-44	Observed	153	136	119	124	109	125
	Exp 1	150.8	128.2	106.9	*155.9*	108.6	122.4
	Exp 2	161.1	126.4	117.5	133.1	112.9	120.4
45-54	Observed	197	204	169	216	199	246
	Exp 1	219.4	178.5	177.2	207.8	190.0	235.0
	Exp 2	197.1	192.0	174.0	213.7	197.7	234.4
55-64	Observed	201	154	163	177	176	205
	Exp 1	189.8	156.8	165.6	*147.3*	*212.0*	203.7
	Exp 2	194.8	150.7	159.6	179.0	178.1	210.5
65-74	Observed	120	98	109	89	172	121
	Exp 1	*149.0*	114.9	116.2	100.7	163.8	120.8
	Exp 2	128.7	109.2	112.9	102.1	193.1	122.6

* Underlined values indicate that the Freeman-Tukey deviate between observed and expected was greater than 2.

hood ratio statistic $G^2 = 106.3$; with 49 df, $P < 0.001$). We could determine where the poor fit occurred by making a cell-by-cell comparison of observed and expected values. It is difficult to do this by visual inspection alone because a difference of a few persons in a small cell is of greater significance than the same difference in a large cell. A suitably transformed function of the differences was used for this purpose. In tables 4 and 5 we do not present the transformed differences themselves, but have underlined the expected values that deviate more than 2 SD from the observed values.

We found 2 large deviations for male subjects, one in Kingston-Harriman, and an excess of older men in St. Louis. For female subjects, we found 2 large deviations in Kingston-Harriman, 2 in Portage, and one in St. Louis. Thus, there might have been some uneven sampling of different age groups in Kingston-Harriman, but the patterns for the other 5 cities were very similar. When we removed Kingston-Harriman and refit the model to the other 5 cities, we got a much better fit ($G^2 = 65.88$; with 40 df, $P = 0.006$); but the same 4 cells had relatively large deviations.

We also computed the expected values obtained when we postulated that the differences in sampling ratio by age varied by sex. The fit was significantly improved but was not good ($G^2 = 90.54$; with 45 df, $P < 0.001$). When we permitted the sampling by age patterns to differ by city, but kept the sex differential constant, the model fit very well ($G^2 = 31.60$; with 29 df, $P = 0.660$). In every cell the estimate, or expected value (Exp 2 in tables 4 and 5), was close to the observed value, and these estimates were not, in general, very different from the estimates previously obtained by assigning a constant age differential across cities.

We also compared the distribution of our respondents' occupations with that given by the 1970 census. We assumed that the 1970 census reflected the persons available for sampling and that the sampling ratio differed by city, and independently by occupation, to get an estimate for each category. This model did not fit very well ($G^2 = 136.37$; with 30 df, $P < 0.001$); but inspection of the Freeman-Tukey deviates provided information about potential sources of bias. In making such an assessment, it is necessary to bear in mind that the census was for the work force more than 16 yr of age, whereas our sample was for persons 25 to 74 yr of age.

The professional category was overrepresented in St. Louis. Craftsmen were underrepresented in Kingston-Harriman and overrepresented in St. Louis and Watertown (table 6). The method used to obtain these estimates required that an overestimate in any row be compensated by underestimates in another row. Thus, apart from the divergencies of the transport operators, who were oversampled in Watertown and undersampled in Steubenville and Topeka, it would